(12) UK Patent Application (19) GB (11) 2 255 535 (13) A

(43) Date of A publication 11.11.1992

(21) Application No 9109943.2

(22) Date of filing 08.05.1991

(71) Applicant
Autoliv Development AB

(Incorporated in Sweden)

Box 104, S-447 00 Vargarda, Sweden

(72) Inventor
Lars Yngve Haland

(74) Agent and/or Address for Service
Forrester Ketley & Co
Forrester House, 52 Bounds Green Road, London, N11 2EY, United Kingdom

(51) INT CL[5]
B60R 21/16 22/44

(52) UK CL (Edition K)
B7B BSB

(56) Documents cited
GB 2232936 A GB 2220620 A GB 1381999 A
EP 0411979 A

(58) Field of search
UK CL (Edition K) B7B BSB
INT CL[5] B60R

(54) **Vehicle impact sensor arrangement**

(57) A vehicle impact sensor arrangement comprises a sensor (1) having a first part (3) adapted to be fixed in position and a second part (9) positioned adapted to move in response to deformation of the outer skin of a motor vehicle. If the second part (9) moves with a predetermined speed a safety device (2) in the form of an air-bag is activated. In response to movement of the second part a stab engages and ignites a pyrotechnic charge (4) which triggers activation of the safety device (2). The arrangement may be positioned in a vehicle side door.

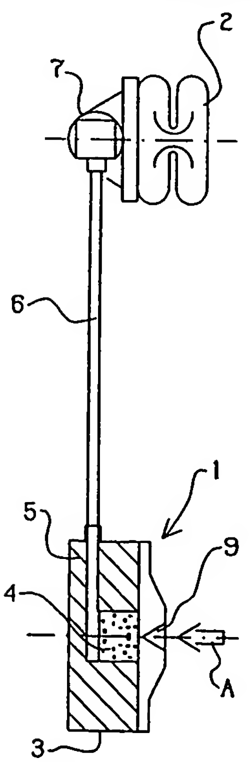
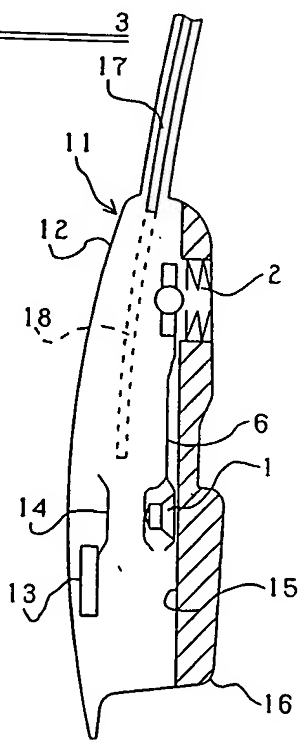


FIG 2

FIG 3



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 255 535 A

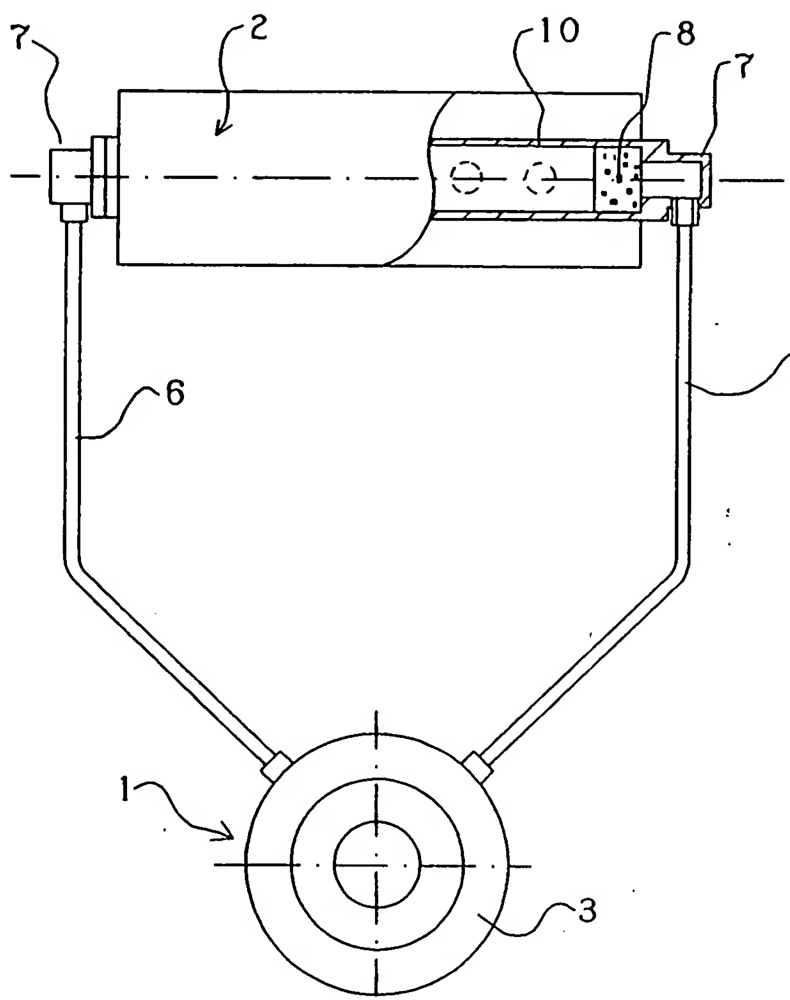


FIG 1

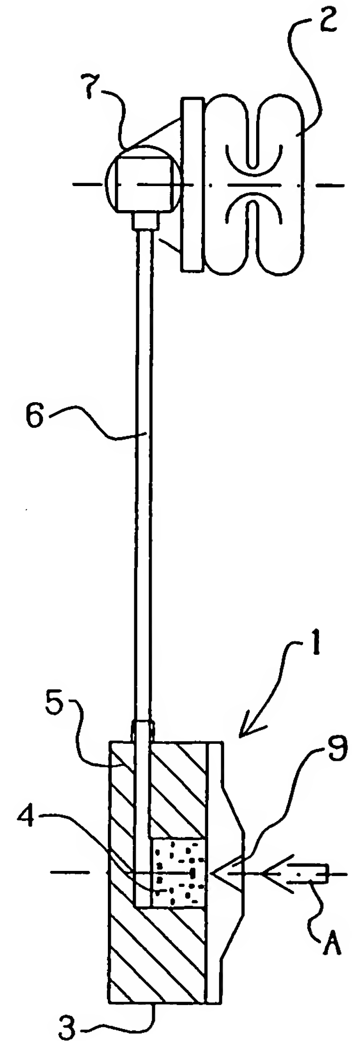


FIG 2

2 / 3

FIG 3

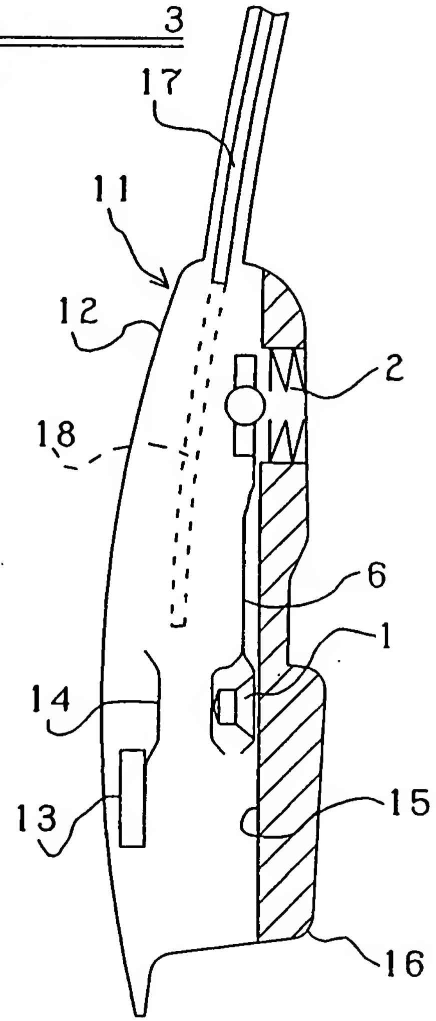
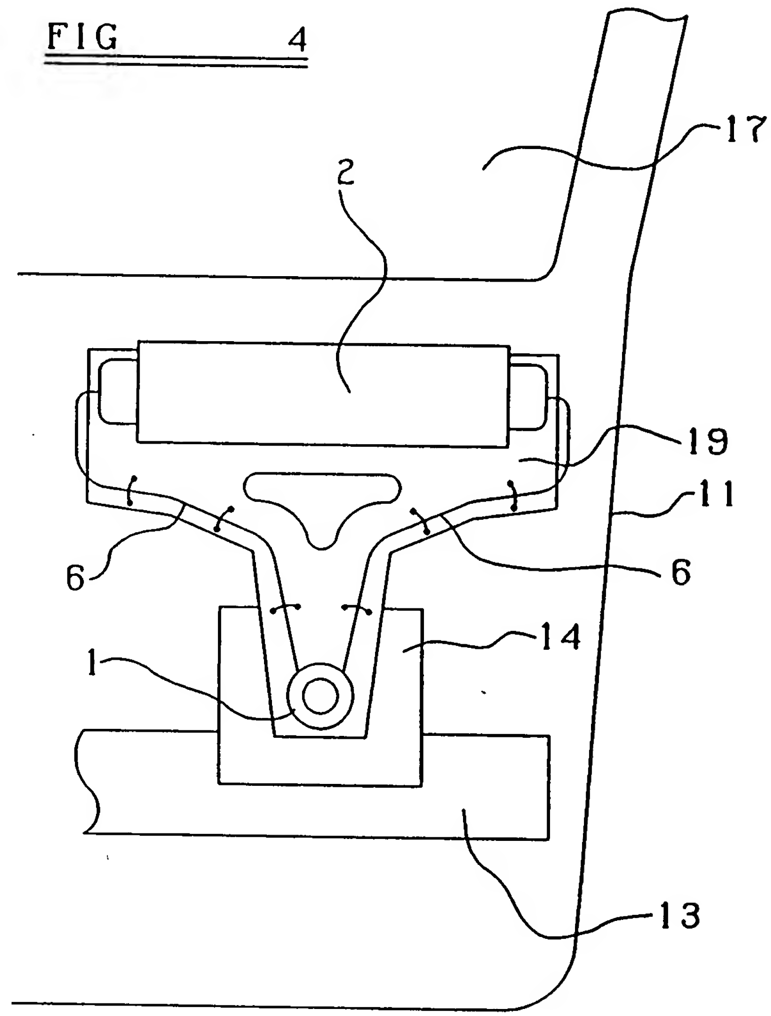


FIG 4



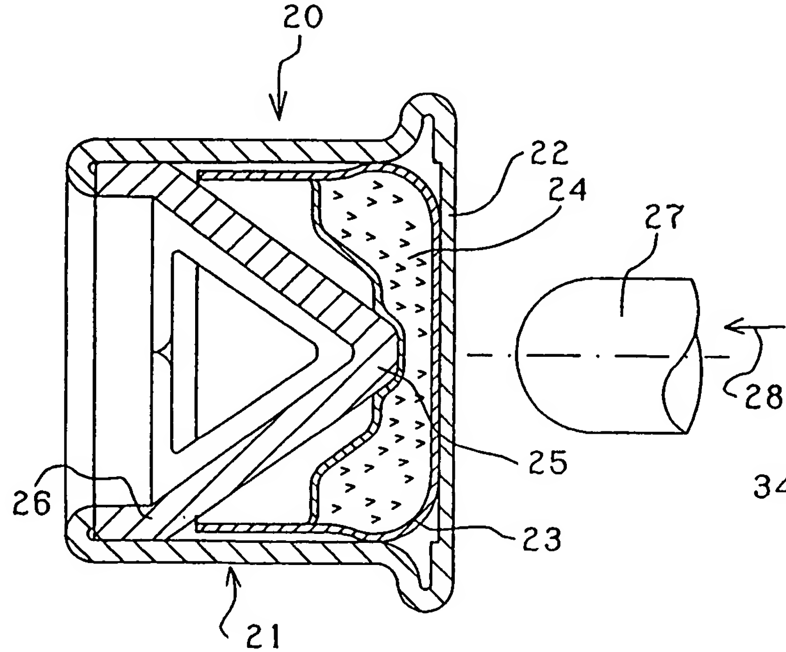


FIG 5

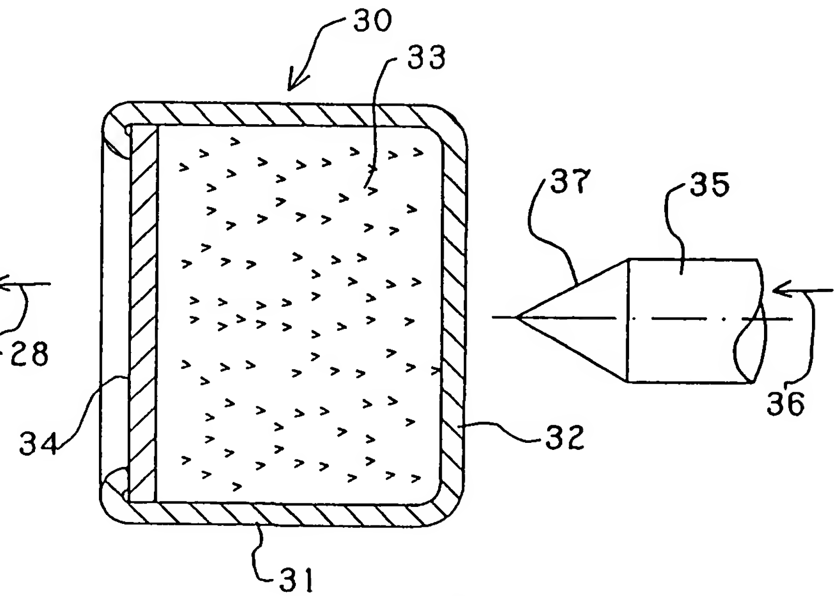


FIG 6

3 / 3

2235535

DESCRIPTION OF INVENTION

"Improvements in or relating to a Vehicle Impact Sensor Arrangement"

THE PRESENT INVENTION relates to a vehicle impact sensor arrangement and more particularly relates to a vehicle impact sensor arrangement adapted to sense an impact on a vehicle and to activate a safety device within the vehicle such as an air-bag or a seat belt pre-tensioner.

When a vehicle, such as a motor car, is involved in an accident, if the vehicle is subjected to an impact or collision, the vehicle can decelerate rapidly. In such a situation a person travelling within the vehicle may continue to move at the original speed of the vehicle, due to inertia and may thus impact with part of the vehicle which has decelerated. For example, if a vehicle is subjected to a front impact, by crashing into a fixed object, the main body of the vehicle may stop relatively rapidly, whilst a person in the vehicle continues to travel forwardly, the person travelling in the vehicle thus, in effect, being thrown forwardly on to a fixed part of the vehicle, such as the steering wheel or the dash board. A similar situation exists if a vehicle is subjected to a side impact.

It has thus been proposed to provide sensors which sense an impact or collision or rapid deceleration of a vehicle, and which activate safety devices such as air-bags or seat belt pre-tensioners.

Many sensors have been proposed previously, and a significant proportion of these sensors operate to provide an electrical signal responsive of the impact. The electrical signal is utilised to trigger the air-bag or the seat belt pre-tensioner. One problem that exists where an electrical triggering system is used is that sometimes a totally "spurious" signal can be generated, due to "noise" or due to external electro-magnetic radiation, which means that the air-bag or seat belt pre-tensioner can be operated when there is no collision or impact. If the car is being driven at the time, this can seriously distract the driver, and indeed, if an air-bag is inflated, the air-bag may well impair the vision of the driver.

A further disadvantage of sensors which provide a "electric" signal is that it is often the case that during a major impact the electrical supply of the vehicle may be impaired very shortly after commencement of the impact. Thus, such sensors may fail to operate satisfactorily in a real accident situation.

During an impact, the outer skin of the vehicle moves relative to a fixed inner part of the vehicle, the chassis of the vehicle. The severity of the impact is related to the speed with which the outer skin of the vehicle moves relative to a fixed part of the vehicle. It is thus desired to be able to provide a sensor which responds to the speed of movement of the outer skin of the vehicle relative to a fixed part of the vehicle, particularly in the case of a sensor adapted and located to detect a side impact.

According to one aspect of this invention there is provided a sensor for sensing an impact on a motor vehicle and for activating a safety device within the vehicle, the

sensor being located between the outer skin of the vehicle and an inner part of the vehicle which is relatively fixed in position, the sensor being adapted to be activated when the outer skin of the vehicle moves at a speed greater than a predetermined speed relative to said fixed part of the vehicle, the device being non-electric.

Preferably the sensor comprises two pasrts, one being supported by the said inner part of the vehicle, the other being located to be moved in response to movement of the outer skin of the vehicle.

According to another aspect of this invention there is provided a sensor for sensing an impact on a vehicle and for activating a safety device in the vehicle, said sensor comprising a first part in the form of a housing containing pyrotechnic material and a second part in the form of a stab, a sensor being located adjacent the outer skin of the vehicle and having one part supported by an inner part of the vehicle which is relatively fixed in position and the other part being adapted to be moved in response to movement of hte outer skin of the vehicle during an impact, the arrangement being such that in an impact situation the stab is moved into an engagement with the housing or the pyrotelchnic material with a speed related to the speed of movement of the outer skin, the arrangement being such that the pyrotechnic material ignites when the speed of movement of the vehicle skin exceeds a predetermined level.

The sensor may be provided in combination with a safety device, the safety device being activated by a pyrotechnic charge. The safety device may comprise an air-bag or a pre-tensioner for a safety belt. The sensor may be connected to the safety device by a high speed fuse or by a shock tube.

Preferably the sensor is mounted in a door of a motor vehicle adapted to respond to a side impact and the safety device is in the form of an air-bag also mounted in the door adapted, when inflated, to be located between the door and a person sitting in the motor vehicle adjacent the door.

In order that the invention may be more readily understood, and so that further features thereof may be appreciated, the invention will now be described, by way of example, with reference to the accompanying drawings in which:

FIGURE 1 is a front view, with parts cut away, of a sensor arrangement in accordance with the invention associated with an air-bag,

FIGURE 2 is a side view, again with parts cut away, of the arrangement of Figure 1,

FIGURE 3 is a sectional view taken through a door of a motor vehicle showing the arrangement of Figures 1 and 2 in use,

FIGURE 4 is a view from the inside of the door, with the inner cladding of the door removed,

FIGURE 5 is a diagrammatic view of one embodiment of percussion initiator, and

FIGURE 6 is a schematic view of another form of percussion initiator for use with the invention.

Referring now to the drawings, Figures 1 and 2 illustrate a sensor arrangement 1 associated with an air-

bag 2. The sensor arrangement 1 consists of a substantially solid housing 3 which defines an inner chamber 4 substantially open to one side of the housing, which contains an appropriate pyrotechnic material. The open end of the chamber may be closed by a thin membrane. Passages 5 leads from the chamber 4, these passages each containing one end of a high speed fuse cord, such as the fuse cord sold under the designation "NONEL". In the embodiment illustrated two passages 5 are provided in the housing, a respective fuse cord 6 passing through each passage. Each fuse cord 6 passes to a gas generator housing 7 which contains a further pyrotechnic charge 8. The gas generator housings 7 are located at opposite ends of a perforated tube 9 which passes through part of the air-bag 2. The air-bag 2 is initially in a collapsed or un-inflated condition.

A stab 9 is provided located adjacent the recess 4 which contains a pyrotechnic material. As will be described hereinafter the sensor 1 is located so that in an impact situation the stab 9 is driven into the recess 4, as generally indicated by the arrow 10. Due to the friction effect between the stab 9 and the pyrotechnic material within the cavity 4, the temperature of teh pyrotechnic material near the stab is elevated and the pyrotechnic material is ignited. The fuses 6 are thus ignited. The fuses form a high speed path for the ignition, and the ignition can travel along this path at speeds between 2,000 and 8,000 metres per second. Consequently, the pyrotechnic charge 8 within each gas generator housing 7 is very rapidly ignited. These pyrotechnic charges generate gas which pass through the apertures formed in the aperture tube 9 to inflate the air-bag 2.

From the description given above it will be appreciated that the described arrangement is totally non-electric, in that no electric signals are utilised whatsoever, and the system is not dependent upon the functioning of the main electric supply system of the vehicle.

Turning now to Figures 3 and 4, the system described above with reference to Figures 1 and 2 is now illustrated in position within a door of a motor vehicle. Thus, the sensor is located in position adapted to sense a side impact. The air-bag is mounted in the door and is adapted to form a cushion between the door and the person sitting adjacent the door in the event that a side impact arises.

Thus Figures 3 and 4 illustrate schematically a door 11 of a motor vehicle. The door presents an outer skin 12, this outer skin being relatively thin and thus being deformed in a side impact. Located adjacent the outer skin 12 is a reinforcing bar 13, and the reinforcing bar 13 carries an extension plate 14. The extension plate 14 is located adjacent the sensor assembly 1 which is fixed in position on the inner skin 15 of the door. The inner skin 15 carries padding and interior lining 16. The high speed fuse 6 is mounted within the interior cavity of the door, and the air-bag 2 is mounted in position on the inside of the door adjacent the lower part of the window 17 provided in the door. The window 17 may be lowered, when it occupies a position 18 as shown in phantom.

Referring now to Figure 4, it can be seen that the sensor 1, the fuses 6 and the air-bag assembly 2 are mounted in position on a support plate 19 which is located in the interior cavity of the door.

It is to be appreciated that in the event that a side impact occurs, the reinforcing bar 13 will be deflected, thus bringing the force transmitting plate 14 into contact with the sensor assembly 1. The sensor assembly will thus be triggered, with the stab engaging the pyrotechnic material, and the air-bag 2 will then be inflated.

Figures 5 and 6 illustrate two alternate embodiments of the sensor which could be used in place of the sensor assembly 1 described above.

Referring initially to Figure 5, a sensor assembly 20 comprises an outer housing 21 of generally cylindrical form having a flexible closed end 22. Contained within the housing is a sack 23 which contains pyrotechnic material 24. The sack rests over the apex 25 of the conical rigid member 26 which is located within the housing 21. The rigid conical member 26 is firmly mounted in position. A stab 27 is provided for use with the arrangement illustrated, the stab being adapted to move towards the flexible end 22 of the cylindrical housing 21 in the direction indicated by the arrow 28 in the event that in impact occurs. The stab 27 will contact the flexible end 22 of the housing and will thus compress a pyrotechnic material 25 against the end 25 of the conical member 26. If the stab is moving with sufficient speed, heat will be generated within the pyrotechnic material as part of the pyrotechnic material is compressed between, effectively, the end of the stab and the apex 25 of the conical member 26. The degree of heat depends upon the speed of compression of the pyrotechnic material and once the appropriate temperature is reached within the pyrotechnic material, the pyrotechnic material 24 will be ignited.

Figure 6 illustrates a modified arrangement 30 in which a cylindrical housing 31 is provided having a closed end 32. The housing contains pyrotechnic material 33 which is retained within the housing by a means of a closure disc 34. A sharp pointed stab 35 is provided for use with this sensor arrangement, the stab moving towards the sensor arrangement in the direction indicated by the arrow 36 in the event of an impact. The pointed end 37 of the stab 35 will penetrate the closure 32 of the cylindrical housing 31, and the pointed end 37 of the stab will then engage the pyrotechnic material 33. A frictional effect will exist between the pointed end 37 of the stab and the pyrotechnic material, this frictional effect generating heat dependent upon the speed of the stab 35 relative to the pyrotechnic material 33. If the speed of the stab is sufficient, the frictional effect will generate sufficient heat to initiate the pyrotechnic material 33.

It is thus to be understood that in the described embodiments of the present invention, the pyrotechnic material within the sensor 1, 20 or 30 is effectively ignited when the speed of the stab 9, 27 or 35 exceeds a predetermined limit. The speed of a stab does exceed this limit the frictional effect between the stab and the pyrotechnic material, or the deformation effect of the pyrotechnic material in the case of the embodiment of Figure 5, is such that the degree of heat generated is adequate to ignite the pyrotechnic material. Of course, a true percussion pyrotechnic material could be used, ignited by the shock wave when the stab engages the pyrotechnic material. Once the pyrotechnic material within the sensor 1, 20 or 30 has been ignited, the high speed fuse 6 will be ignited and will almost instantaneously ignite the pyrotechnic charge 8 within the gas generator 7 of the air-bag 2.

Whilst the invention has been described with reference to certain embodiments it is to be appreciated that many modifications may be effected without departing from the scope of the invention. Instead of using a high speed detonator fuse, it would be possible to utilise a "shock tube" between the sensor and the pyrotechnic charge in the gas generator. In this type of arrangement the pyrotechnic material present within the sensor would be adapted to detonate on activation of the sensor, thus generating a shock wave. The pyrotechnic material in the gas generator would be selected to be triggered by such a shock wave. A shock tube would serve to transfer the shock wave from the pyrotechnic material in the sensor to the pyrotechnic material in the gas generator.

Whilst the invention has been described with specific reference to an arrangement to detect a side impact, the invention is not restricted to such an arrangement, since the invention could be utilised to detect a front impact or a rear impact. Also, while the invention has been described with reference to the inflation of an air-bag in response to a sensed impact, it is to be appreciated that the sensor of the invention may be utilised in conjunction with a seat belt pre-tensioner.

It is to be appreciated that the sensor of the invention is adapted to be mounted in position between a fixed part of the vehicle and the outer skin of the vehicle, and is responsive to the speed of deformation of the outer skin of the vehicle relative to the fixed part of the vehicle. If the speed of deformation is not large, the stab will not generate sufficient heat to activate the pyrotechnic material and thus the sensor will not activate the safety device. It is only when the speed of deformation of the skin of the vehicle is sufficiently

great to generate the necessary heat within the pyrotechnic material to ignite the pyrotechnic material that the sensor activates the safety system.

CLAIMS:

1. A sensor for sensing an impact on a motor vehicle and for activating a safety device within the vehicle, the sensor being located between the outer skin of the vehicle and an inner part of the vehicle which is relatively fixed in position, the sensor being adapted to be activated when the outer skin of the vehicle moves at a speed greater than a predetermined speed relative to said fixed part of the vehicle, the device being non-electric.

2. A sensor arrangement according to Claim 1 wherein the sensor comprises two parts, one being supported by the said inner part of the vehicle, the other being located to be moved in response to movement of the outer skin of the vehicle.

3. A sensor for sensing an impact on a vehicle and for activating a safety device in the vehicle, said sensor comprising a first part in the form of a housing containing pyrotechnic material and a second part in the form of a stab, a sensor being located adjacent the outer skin of the vehicle and having one part supported by an inner part of the vehicle which is relatively fixed in position and the other part being adapted to be moved in response to movement of the outer skin of the vehicle during an impact, the arrangement being such that in an impact situation the stab is moved into an engagement with the housing or the pyrotechnic material with a speed related to the speed of movement of the outer skin, the arrangement being such that the pyrotechnic material ignites when the speed of movement of the vehicle skin exceeds a predetermined level.

4. A sensor according to Claim 3 in combination with a safety device, the safety device being activated by a pyrotechnic charge.

5. A sensor and safety device combination according to Claim 4 wherein the safety device is an air-bag.

6. A sensor and safety device combination according to Claim 4 wherein the safety device is a pre-tensioner for a safety belt.

7. A sensor and safety device combination according to any one of the Claims 4 to 6 wherein the sensor is connected to the safety device by a high speed fuse.

8. A sensor and safety device combination according to any one of Claims 4 to 6 wherein the sensor is connected to the safety device by means of a shock tube.

9. A safety device and sensor combination according to any one of Claims 4 to 8 wherein the sensor is mounted in a door of a motor vehicle adapted to respond to a side impact and the safety device is in the form of an air-bag also mounted in the door adapted, when inflated, to be located between the door and a person sitting in the motor vehicle adjacent the door.

10. A sensor arrangement substantially as herein described with reference to Figures 1 to 4 of the accompanying drawings.

11. A sensor device substantially as herein described with reference to and as shown in Figures 1 to 4 as modified by Figure 5 of the accompanying drawings.

12. A sensor device substantially as herein described with reference to and as shown in Figures 1 to 4 of the accompanying drawings as modified by Figure 6.

13. Any novel feature or combination of features disclosed herein.

CLAIMS:

1. A sensor arrangement for sensing an impact on a motor vehicle and for activating a safety device within the vehicle, comprising sensor being located between the outer skin of the vehicle and an inner part of the vehicle which is relatively fixed in position, the sensor being adapted to initiate activation of the safety device only when the outer skin of the vehicle moves at a speed greater than a predetermined speed relative to said fixed part of the vehicle, the arrangement being non-electric.

2. A sensor arrangement according to Claim 1 wherein the sensor comprises two parts, one being supported by the said inner part of the vehicle, the other being located to be moved in response to movement of the outer skin of the vehicle.

3. A sensor for sensing an impact on a vehicle and for activating a safety device in the vehicle, said sensor comprising a first part in the form of a housing containing pyrotechnic material and a second part in the form of a stab, the sensor being located adjacent the outer skin of the vehicle and having one part supported by an inner part of the vehicle which is relatively fixed in position and the other part being adapted to be moved in response to movement of the outer skin of the vehicle during an impact, the arrangement being such that in an impact situation the stab is moved into an engagement with the housing or the pyrotechnic material with a speed related to the speed of movement of the outer skin, the arrangement being such that the pyrotechnic material ignites when the speed of movement of the vehicle skin exceeds a predetermined level.

Patents Act 1977
F--aminer's report to the Comptroll r under Section 17 (The Search Report)

Application number

9109943.2

Relevant T chnical fields

(i) UK Cl (Edition K) B7B (BSB)

(ii) Int Cl (Edition 5) B60R

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

PAT EVERETT

Date of Search

16 SEPTEMBER 1991

Documents considered relevant following a search in respect of claims 1-12

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2232936 (AUTOLIV) - page 4 lines 14-27	1
X	GB 2220620 (GENERAL ENGINEERING) - page 7 lines 1-15	1
X	GB 1381999 (PORSCHE) - page 2 lines 32-35	1
X	EP 0411979 (RENAULT) - Figures 3 and 4	1

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

Published 1992 at The Patent Office, Concept House, Cardiff Road, Newport, Gwent NP9 1RH. Further copies may be obtained from Sales Branch, Unit 6, Nine Mile Point, Cwmfelinfach, Cross Keys, Newport, NP1 7HZ. Printed by Multiplex techniques ltd. St Mary Cray, Kent.

SAE TECHNICAL PAPER SERIES

920124

A Critique of Single Point Sensing

David S. Breed, W. Thomas Sanders, and Vittorio Castelli
Automotive Technologies International, Inc.

Reprinted from: Analytical Modeling and Occupant Protection Technologies (SP-906)

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL®

International Congress & Exposition
Detroit, Michigan
February 24-28, 1992

400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096-0001 U.S.A.

920124

A Critique of Single Point Sensing

David S. Breed, W. Thomas Sanders, and Vittorio Castelli
Automotive Technologies International, Inc.

Abstract

In two previous SAE papers (1,2) by the authors, supporting analysis was presented showing the difficulty in achieving a timely response to real-crash events using a single point sensor mounted in the non-crush zone of the vehicle (tunnel, cowl, etc.). The analysis demonstrated the propensity to deploy the air bag(s) late during certain of these events. If a vehicle occupant was not wearing a safety belt, the deceleration forces of the crash could place the occupant out of position and resting against the air bag when it was deployed. In another SAE paper (3) by H. J. Mertz et al, the authors demonstrated that animals, used as surrogates for humans, could be injured if positioned against an air bag at the time of deployment.

Arguments are presented here to show that there is insufficient information in the crash pulse as sensed in the non-crush zone to deploy an air bag in time for the unbelted occupant. It is therefore not possible to create an algorithm for an electronic sensor, based on the crash pulse information in the non-crush zone alone, which will initiate air bag deployment in time for all cases. Therefore, sensing in the crush zone is required.

Most air bag equipped vehicles on the road today have distributed sensor systems with at least one sensor located in the crush zone. There is now a trend to replace distributed sensor systems with a single "smart" sensor located in the passenger compartment. This is referred to as Single Point Sensing. In previous papers [4,5], the authors have presented examples where, in their opinion, it was not possible to discriminate crashes based on the passenger compartment crash pulses. They have also presented an analytical scaling technique for testing any proposed sensor algorithms. Several companies now claim that they have found an algorithm that works, but little has been published and no demonstrations have been presented using scaling techniques to substantiate these claims.

The authors have continued to examine the possibility of Single Point Sensing and have concluded that there is not sufficient information in the crash pulse, as measured anywhere except in the crush zone, to permit reliable crash sensing at least for the case where the occupant is not wearing a safety belt. As discussed in detail elsewhere [1-5], the crush zone can be defined as that portion of the vehicle which has substantially reached its final post crash velocity at the time that the crash sensor is required to initiate the deployment of the air bag.

The purpose of this paper is to present the reasoning behind this conclusion in the hope that it will lead to an open discussion of sensor strategies which will either prove the authors to be in error, or prevent the wide spread introduction of single point sensing systems which the authors believe could lead to unnecessary injury. The most common failure of single point sensing systems, the authors believe, will be in causing the air bag to deploy late when the occupant is out of position and dangerously near the air bag when deployment commences. If the electronic sensor disables the system to prevent these late deployments, occupants could be injured by not having the protection of the air bag. It is not the purpose of this paper to assess the probability of injury such as can be caused by interaction with a deploying air bag, but this possibility has been documented in the literature [6].

Briefly, the argument against single point sensing can be summarized by the following four points:

- Car company crash libraries used to design sensors are significantly different from real world crashes.
- Real world crash pulses are usually significantly longer and more varied.
- Because of this variability, it is not possible to predict the velocity change of a crash except where the car is crushing.
- This is independent of the vehicle and cannot be fixed by structural modifications.

TABLE 1

PERFORMANCE OF A SINGLE POINT NON-CRUSH ZONE MOUNTED DISCRIMINATING SENSOR
TYPICAL TEST SERIES

CRASH DESCRIPTION	REQUIREMENT	TRIGGER TIME
8 MPH - FRONTAL BARRIER	NO TRIGGER	NO TRIGGER
8 MPH - FRONTAL BARRIER	NO TRIGGER	NO TRIGGER
14 MPH - FRONTAL BARRIER	51	56
14 MPH - FRONTAL BARRIER	42	53
14 MPH - FRONTAL BARRIER	40	47
14 MPH - POLE (DATA BAD)	--	--
30 MPH - OFFSET BARRIER (DATA BAD)	--	--
31 MPH - 30 DEGREE LEFT BARRIER	36	33
31 MPH - 30 DEGREE LEFT BARRIER	25	21
31 MPH - 30 DEGREE RIGHT BARRIER	34	34
31 MPH - 30 DEGREE RIGHT BARRIER	33	33
31 MPH - 30 DEGREE RIGHT BARRIER	28	23
31 MPH - FRONTAL BARRIER	25	21
31 MPH - FRONTAL BARRIER	24	23
31 MPH - FRONTAL BARRIER	22	20
31 MPH - FRONTAL BARRIER	23	23
31 MPH - FRONTAL BARRIER (DATA BAD)	--	--
31 MPH - FRONTAL BARRIER (DATA BAD)	--	--
31 MPH - OFFSET POLE	51	59
35 MPH - FRONTAL BARRIER	26	23
35 MPH - FRONTAL BARRIER	22	21
35 MPH - FRONTAL BARRIER	23	22
35 MPH - FRONTAL BARRIER	23	21
35 MPH - FRONTAL BARRIER	22	21
35 MPH - FRONTAL BARRIER	21	22

VEHICLE MANUFACTURER CRASH LIBRARIES COMPARED WITH REAL CRASHES

Table 1 lists a series of 25 crashes which were conducted by a vehicle manufacturer as part of the process of developing and testing an air bag system for a particular vehicle. Unfortunately, the data on four of the crashes were unusable. Figure 1 shows a plot of the velocities of the vehicles in the crashes listed in Table 1 where the data was good. The vehicle front end structure was changed midway through the test sequence, which shortened the crash pulse by about 10 milliseconds and explains why there appears to be two groupings of the data. Even though there appears to be some variety in the crashes chosen, the shapes of the velocity curves are quite similar, with one exception, during the early portion of the pulse when the sensor must trigger. The one exception represents the 31 MPH Offset Pole crash.

Table 1 also contains columns showing the sensor required triggering time and the time that a particular simple mechanical sensor would have triggered based on simulations. As can be seen, this simple sensor does a very good job in triggering in time on all but a few low velocity crashes where some delay can be tolerated.

TABLE 2

PERFORMANCE OF A SINGLE POINT NON-CRUSH ZONE MOUNTED DISCRIMINATING SENSOR
CRASHES REPRESENTATIVE OF REAL WORLD

CRASH DESCRIPTION	REQUIREMENT	TRIGGER TIME
8 MPH - FRONTAL BARRIER	NO TRIGGER	NO TRIGGER
14 MPH - FRONTAL BARRIER	29	30
35 MPH - OFFSET POLE 8" OFF CENTER	30	21
14 MPH - OFFSET POLE 14" OFF CENTER	73	146
12 MPH - 8 INCH OFFSET POLE	64	125
18 MPH - 50% OFFSET TRUCK UNDERRIDE	60	100
35 MPH - NHTSA DEFORMABLE BARRIER BOTH MOVING	39	60
27 MPH - VEHICLE TO VEHICLE FRONT TO FRONT 25% OVERLAP	41	73
26 MPH - VEHICLE TO VEHICLE LEFT FRONT TO RIGHT FRONT TARGET	44	NO TRIGGER
28 MPH - VEHICLE TO VEHICLE LEFT FRONT TO CENTER FRONT BULLET	53	NO TRIGGER
27 MPH - VEHICLE TO VEHICLE WITH 25% OVERLAP	47	NO TRIGGER
22 MPH - VEHICLE TO VEHICLE 90 DEG A-PILLAR BOTH CARS MOVING	NO TRIGGER	56

It is difficult to get a library of more realistic crashes of the same vehicle, since real world type crashes are rarely staged by the automobile manufacturers. Nevertheless, one manufacturer did attempt to generate such a library as listed in Table 2, and plotted in Figure 2. Although it is easy to imagine a much larger spectrum of crashes than shown in Table 2, this still illustrates that the diversity, even in this small library, is much greater than shown in Table 1. In contrast to the case of Table 1, it is not obvious how to design a sensor, even using a complicated algorithm, which will distinguish between those crashes in Table 2 where the air bag is required and those where it is unwanted.

Figures 1A and 2A display the velocity changes of these libraries as seen by the sensor, and Figures 1B and 2B show these velocity changes amplified. In Figures 2A and 2B, the 22 MPH vehicle-to-vehicle no-trigger case was not plotted. In Figure 1B, all of the crash pulses are above the 8 MPH no-trigger pulse before 55 milliseconds.

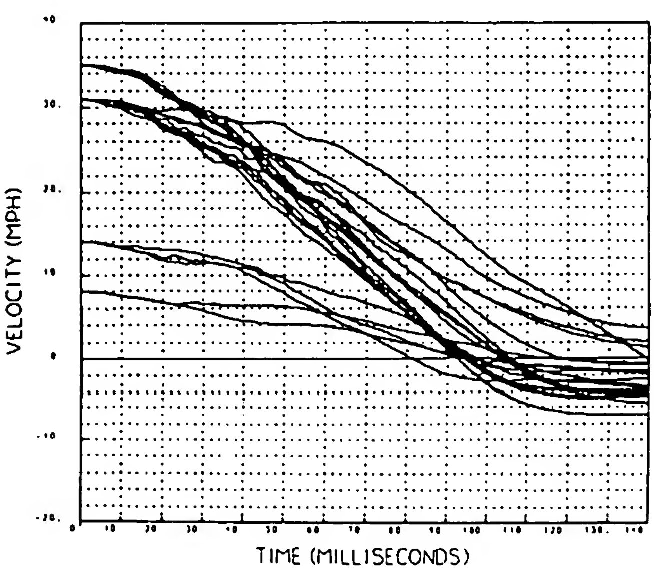


FIG. 1. Crash Library For Full Size American Car - 1989 Typical Test Series.

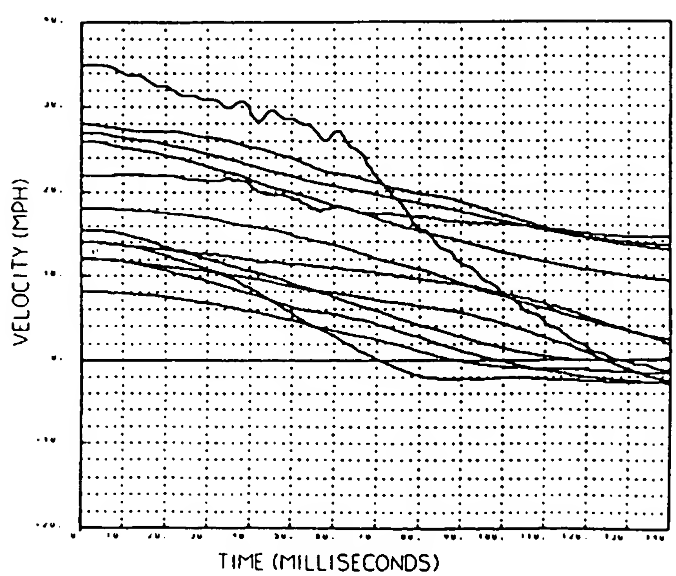


FIG. 2. Crash Library For Full Size American Car - 1989 Representative of Real World.

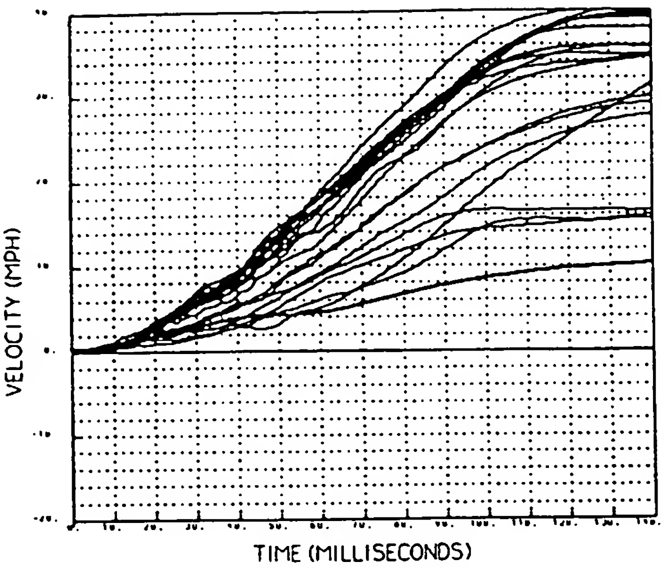


FIG. 1A. Crash Library For Full Size American Car - 1989 Typical Test Series.

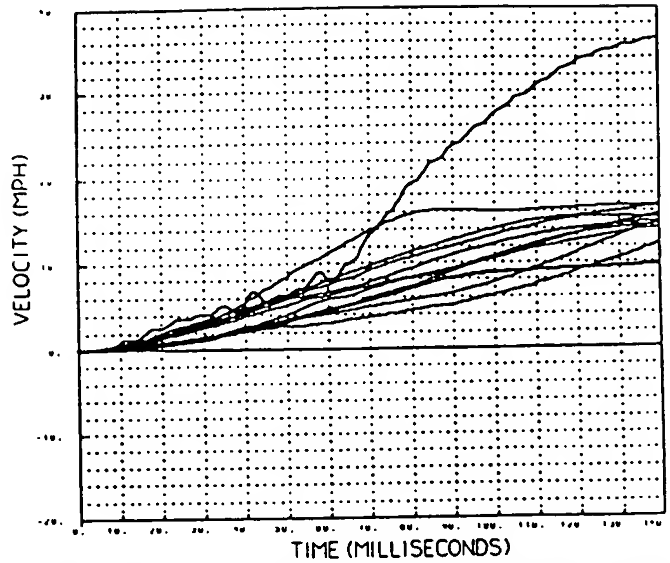


FIG. 2A. Crash Library For Full Size American Car - 1989 Representative of Real World

This is not the case in Figure 2B where two pulses never are above the 8 MPH case, and one oscillates back and forth around the 8 MPH case. Therefore, it is unlikely that any algorithm will perform correctly on the crashes of Figure 2B.

The argument has been made that in some real world crashes even with large velocity changes, it may not be necessary to deploy the air bag since the occupant may already be resting against the steering wheel or instrument panel and, therefore, able to ride down the accident. It is concluded that it is not the total velocity change of the accident that is important, but the relative velocity of the occupant at the time he collides with the passenger compartment; the so called "Second Collision".

The relative velocity at the Second Collision is dependent on the initial distance of the occupant from the steering wheel or instrument panel, and the magnitude, shape and duration of the crash pulse. In order to simplify this problem, we will assume that the shapes of all crash pulses are more or less the same, at least during the early part of the pulse. This assumption is explored in more detail in [4]. Limited observations and measurements have shown that some small drivers (such as the 5% female) are positioned as close as 4 inches from the steering wheel and some passengers are displaced more than 30 inches from the instrument panel. A typical 50% male driver, however, is frequently assumed to be positioned about 12 inches from the steering wheel and about 24 inches from the instrument panel, and these values will be used here.

Figure 3 is a plot of two families of curves, one for the driver and one for the passenger. They show the Second Collision velocity for various impact velocities and various pulse periods relative to the barrier crash

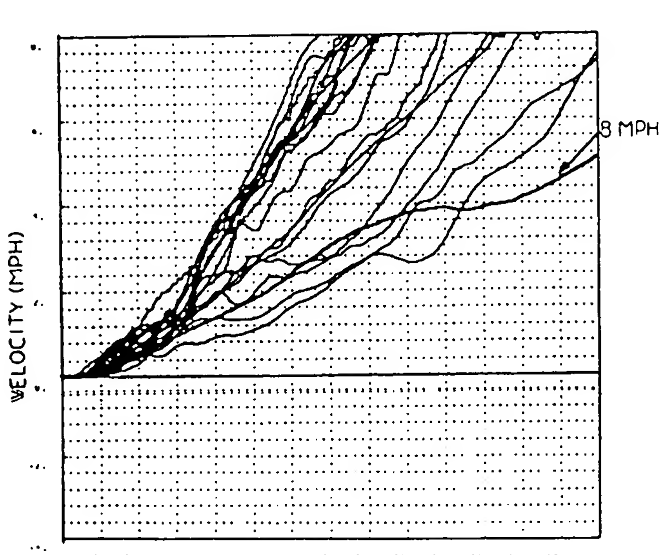


FIG. 1B. Crash Library For Full Size American Car - 1989 Typical Test Series.

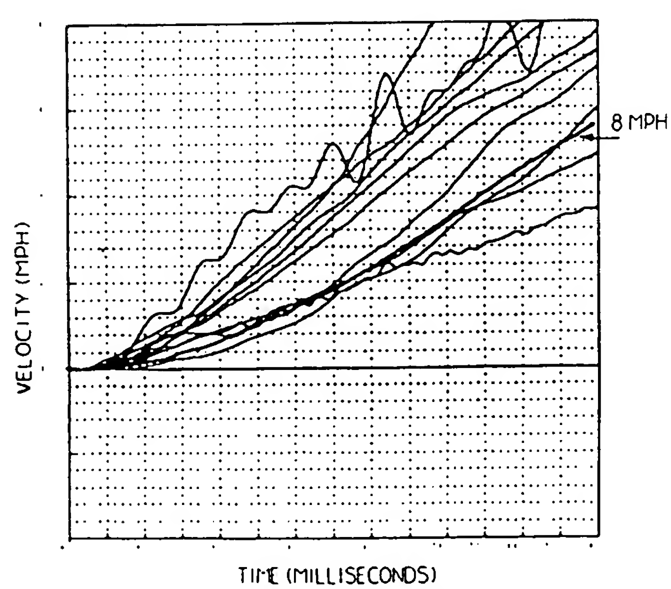


FIG. 2B. Crash Library For Full Size American Car - 1989 Representative of Real World.

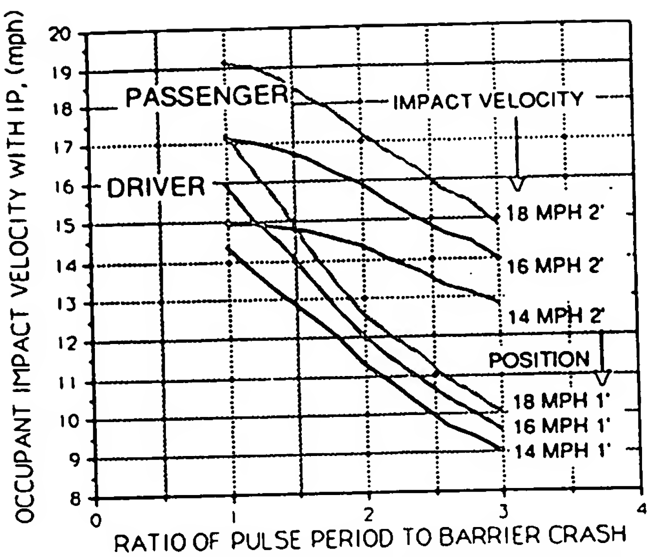


FIG. 3. Unrestrained Occupant to Instrument Panel (Passenger) or Steering Wheel (Driver) Velocities For Soft Crashes.

period. For example, if a driver, traveling at 16 MPH and positioned at 12 inches from the steering wheel, is involved in an accident where the period is twice that of a barrier crash, he will strike the steering wheel at 12 MPH. Most real world crashes have a period of between one and three times that of a barrier crash, and thus, for all crashes 14 MPH or above for the passenger and most of them for the driver, the Second Collision will be above 12 MPH.

Figure 3 was based on a vehicle having a barrier crash pulse period of 85 milliseconds and was determined using crash and velocity scaling techniques described in [2,4]. Based on this analysis, therefore, the velocity of the Second Collision is nearly the same as the velocity of the vehicle, with some reduction as the occupant is positioned closer to the instrument panel and as the crash becomes softer.

It is the velocity of the Second Collision that causes injury or death to the occupant and it doesn't matter whether the crash was a soft crash or a barrier crash. If the vehicle is still decelerating at the time of the second collision, the situation could only be worse, depending on the level of deceleration, and thus this analysis is conservative. This is because the occupant would still see the injury caused by his change in velocity upon impact followed by a possible additional injury caused by his ride down. From Figure 3 we see that the velocity change of the vehicle is the best indicator of the velocity of the Second Collision, and therefore, crash sensors should determine whether this velocity change is above the injury threshold or not.

As discussed above, the vehicle during a crash can be divided into two parts, the crush zone and the non-crush zone. By definition, the crush zone has changed its velocity by an amount approximately equal to the velocity change of the crash at the time that the sensor is required to trigger the air bag. Sensors mounted in the crush zone, therefore, should have a response which is equal to the velocity change of the vehicle for barrier crashes and can be a little less responsive as the crash gets softer. The proper response of the crush zone sensor is therefore known, and the designer does not need to know anything about the vehicle structure or the shape of the crash pulse. That is, it is independent of the vehicle.

Single point sensors are not, in general, located in the crush zone and the problem is that there is no simple relationship between the velocity change of the non-crush zone at the time that the sensor is required to trigger and the Second Collision velocity. In some air bag desired crashes, for example, this velocity change can be as low as 2 MPH and in others as high as 8 MPH. Also, the sensor must not go off on an 8 MPH barrier crash. It is also hard to imagine that there is any other parameter of a non-crush zone crash pulse that serves as a reliable predictor of the Second Collision velocity. Some possible parameter choices will be discussed below.

In contrast to crush zone sensing, there is no theoretical or intuitive reason to believe that there is any predictive information in the non-crush zone crash pulse. Lacking such a theory, sensor designers have resorted to looking at crash libraries and fitting a sensor response to the requirements of that crash library. To the extent that the particular library used does not represent real world crashes, the resulting sensor system can be expected to fail in use.

PULSE STRETCHING AND SHORTENING

The most significant difference between the crash pulses shown in Figures 1 and 2 is the period of these pulses. As an example of why the pulse periods are different, consider the following experiment involving four identical vehicles: A, B, C and D.

Crash vehicle A into a barrier at 8 MPH, the chosen non-deployment velocity for one vehicle manufacturer. The velocity change will be similar to that shown in Figure 4.

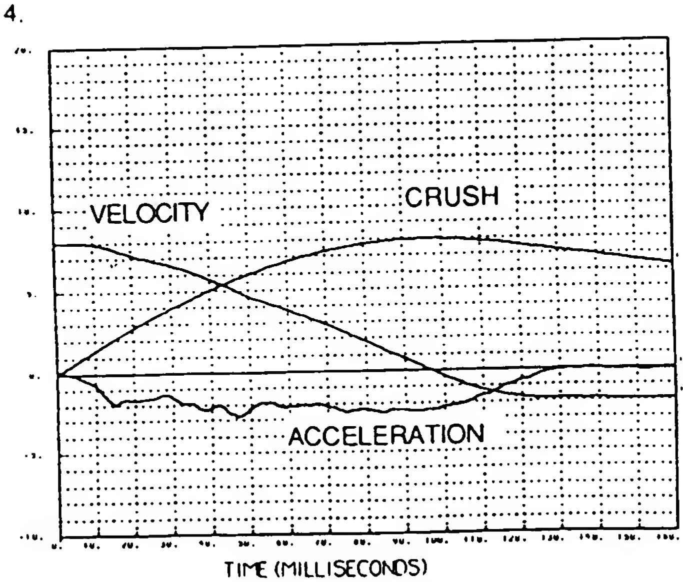


FIG. 4. 8 MPH Frontal Barrier Crash Passenger Compartment Location.

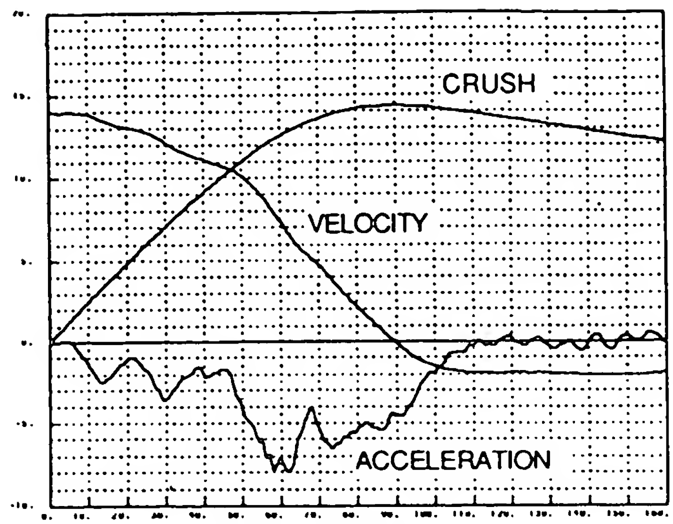


FIG. 5. 14 MPH Frontal Barrier Crash Passenger Compartment Location.

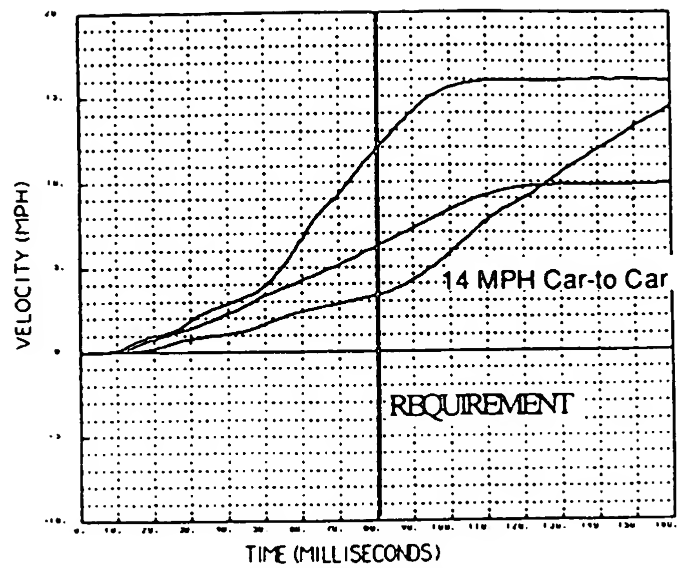


FIG. 8. 8 MPH Barrier, 14 MPH Barrier and 14 MPH Car-to-Car Velocities.

Crash vehicle B into a barrier at 14 MPH, the chosen required deployment velocity, and the velocity change will be similar to that shown in Figure 5, where the velocity change is about 16 MPH.

Now place Vehicle C against and pointed toward the barrier and crash vehicle D into it at 14 MPH as shown in Figure 6. The velocity change crash pulse for this case will be similar to Figure 7, which was formed by crash scaling, for the following reasons:

It is well documented from accident reconstruction theory [7] that the exterior of a vehicle can be represented by a series of springs, in order to determine the velocity change of the vehicle based on damage. Three sets of such springs will be involved in this experiment representing the front of the moving vehicle and the front and rear of the stopped vehicle. If we assume that they are identical in stiffness (the rear of a vehicle is actually much softer), the deceleration of the moving vehicle will be determined by three sets of springs in series as opposed to one set for the frontal barrier case.

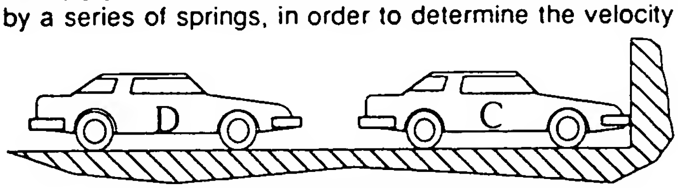


FIG. 6. Car Into Stationary Car Into Barrier

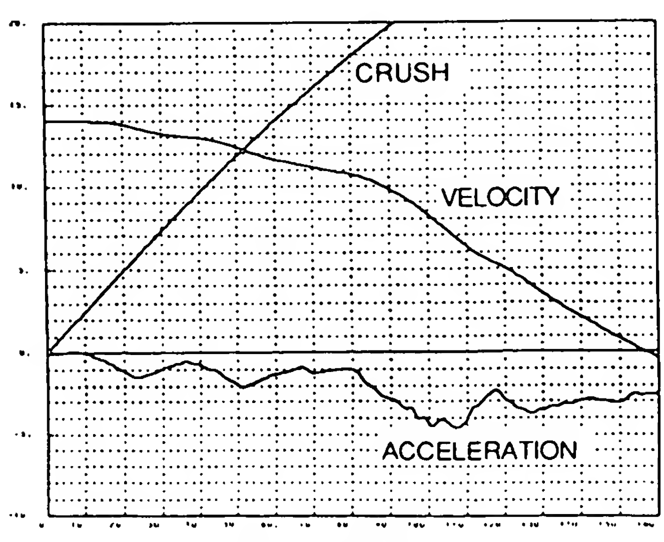


FIG. 7. 14 MPH Front to Rear Car-to-Car Crash.

The period of the pulse (the duration of the crash) is proportional to $\sqrt{(M/K)}$. For this case the combined spring constant is equal to 1/3 of the barrier case, if we assume that the rear of the resting vehicle has the same stiffness as its front and that we can neglect the mass of the stopped vehicle. Thus the new crash duration = $\sqrt{3}$ times the barrier crash duration or 158 milliseconds if the barrier pulse had a duration of 91 milliseconds. This crash pulse will appear similar to that of Figure 7.

If the velocity plots of Figures 4, 5 and 7 are superimposed and plotted along with the sensor triggering requirement, based on the time of a free mass motion of 5 inches minus 30 milliseconds of inflation time, the velocity change at the required triggering time for Figure 6 is substantially less than that of Figure 4. Yet the Second Collision velocity is the same as in Figure 5, and therefore an air bag deployment is required. This is illustrated in Figure 8.

Since these are all barrier crashes, it is unlikely that any other crash pulse parameter, such as vibrations, will permit a distinction to be made between these two cases and, therefore, it is unlikely that this distinction can be made with any non-crush zone mounted sensor.

On the other hand, in both cases 5 and 7, but not in case 4, some part of the vehicle has undergone the 14 MPH velocity change at the time that air bag deployment is required. That part is, by definition, the crush zone. Thus, crush zone sensors can discriminate between these crashes but non-crush zone sensors cannot regardless of the algorithm used. If the sensor system is turned off so as to prevent a late deployment in case 7, the occupant

could be injured.

Analysis, similar to Figure 3, shows that an unrestrained driver located 12 inches from the steering wheel will strike it at about 13 MPH, and an unrestrained passenger located 24 inches from the windshield will strike it at 16 MPH for a 155 millisecond 14 MPH (16 MPH velocity change) crash pulse. Also, this analysis is conservative since car rear structures are much softer than car front structures. It is not conservative to the extent that the mass of the stopped vehicle comes into play. This is also a common crash situation and simulates the case of a multiple accident on a foggy highway. A real crash example of a similar case will be presented below.

In the early 1980's, one automobile manufacturer made an estimate of the distribution of air bag desired accidents by accident type as shown in Table 3. From this table it can be seen that frontal barrier crashes, which dominate the crash library of Table 1, account for only 2% of real world accidents. The angle barrier crashes, which make up 24%, are at a wide variety of speeds and angles and thus quite different from the 31 MPH 30° staged crashes.

A significant difference between the crashes of Table 3 and Table 1 is the degree of involvement of the front end of the vehicle. In a recent visit to the Tech-Cor, Inc. vehicle holding yard, the authors made an informal survey of 100 randomly chosen vehicles which had been totaled in frontal impacts. They found that approximately 40% were frontal underride accidents where, in many cases, there was little or no damage to the bumper. Since the bumper is the stiffest part of the front end of the vehicle, these accidents were undoubtedly considerably softer than the crashes of Table 1 where every crash involved the bumper. In one case, only the bumper was involved and in another case the bumper over-rode in the accident so that structure below the bumper was primarily involved. This last accident was also probably softer than those of Table 1. All of these accidents result in a stretching of the crash pulse and may or may not alter the characteristic shape of the barrier pulse. It is interesting to note that even in Table 2 only one crash did not involve the bumper. The incidence of the bumper over-ride case is probably much more common than the 1% observed since many front-to-front car-to-car accidents will involve the bumper of one over-riding the bumper of the other, giving rise to one over-ride and one under-ride case.

TABLE 3

SURVEY OF REAL WORLD ACCIDENTS IN THE 1970'S

TEST CONDITION	% FIELD ACCIDENTS
Frontal Barrier	2
Partial Barrier	2
Bumper Underride	4
Partial Underride	7
On-Center Pole	5
Off-Center Pole	9
Off-Center Low Pole	1
Partial Car-to-Car	14
Frontal Car-to-Car	11
Angle Car-to-Car	13
Angle Barrier	24
Angle Hinge Pillar Car-to-Car	5
Undercarriage Hangup	3

As reported in [3] for side impacts, when a vehicle strikes a movable object having a different stiffness to mass ratio than the striking vehicle, the period of the crash pulse can either increase or decrease. A soft heavy object will stretch the pulse and a light stiff object will result in a shortened pulse. Naturally, the many forms of crash attenuators which are placed around rigid objects also have a significant effect in stretching the crash pulse. Impacts which result in stretching the pulse, as discussed above, can lead to a late air bag deployment, and impacts which shorten the pulse can result in unwanted deployments for those crash sensors which rely on the slope of the velocity curve in the non-crush zone. This includes all electro-mechanical and probably most electronic crash sensors.

Other impacts which can result in a very short pulse with a small velocity change include impacts with break-away poles, high speed animal impacts and undercarriage bottoming out. The first two would not only defeat non-crush zone sensors but would probably also defeat currently used sensors in the crush zone.

To summarize, non-crush zone sensors cannot rely on the velocity pulse alone since it is not possible to distinguish between shortened pulses where the air bag is not desired, barrier pulses where the air bag is not desired, barrier pulses where the air bag is desired, and soft crashes where it is desired.

INFORMATION AND TRANSFER FUNCTIONS

An alternate way of looking at the problem of sensing in the passenger compartment is as follows. A car is experiencing a crash of a certain severity at the front of the vehicle and the problem is to determine that severity using the pulse measured in the passenger compartment. This requires a knowledge of the transfer function between the place where the vehicle is crushing and the sensor location. In other words, when the vehicle is crushing in the front and decelerating everywhere else, what is the mathematical relationship between the deceleration of the vehicle and the phenomena at the point where the car is crushing.

In some cases the entire front of the vehicle is crushing, as in a barrier crash, while in others only a portion is crushing as in pole, bumper over-ride or angle bumper under-ride crashes. Thus, there is no single transfer function but a large number of different ones. In some cases the velocity change information is transmitted rapidly to the rest of the car while in others it takes a long time. A low velocity crash where the information is rapidly transmitted is indistinguishable from a high velocity slowly transmitted crash.

Also, in some cases the object being struck is rigid while in others it is soft so that even if all of the transfer functions were accurately known and incorporated into an algorithm, it would still be difficult to distinguish

between a high speed impact into a soft object and a low speed impact into a rigid object. The two pulses could look exactly the same in the passenger compartment until long after the sensor required trigger time has passed, with one pulse stopping after a velocity change of 8 MPH while the other continues to a velocity change of 20 MPH, for example.

If velocity change alone is not adequate, could some other parameter of the crash pulse work? The rate of change of acceleration, for example, has been proposed, but this also must be strongly dependent on the transfer function from the site of the impact to the sensor. Alternatively the average acceleration has been proposed which is really the slope of the velocity curve, and has been discussed above.

The integral of the velocity, the displacement, might be of some value since it gives an indication of the position of an occupant as represented by a free mass. If the displacement exceeds a certain value indicating that the occupant is approaching the air bag, then the air bag might be prevented from deploying. Such an algorithm would need to have a different criterion for the driver than for the passenger, and probably should have an input as to where the seat is positioned and as to whether the occupants are wearing safety belts. In any case, such an algorithm could only function to minimize late deployments and could not be used to determine that the air bag should be deployed. Thus, the air bag might not be deployed when it is required. The information is available in the crush zone, however, and a crush zone sensor could deploy the air bag in time.

Anyone familiar with crash pulses cannot help but be impressed by the level of vibrations usually present. It is very tempting to believe that there is some information in these vibrations that can be used to distinguish air bag desired crashes from the others. Therefore, it is worth considering whether there is some logical reason for believing that it might work.

One theory might be that particular frequencies are excited by the crushing of certain structural members, and that the presence of a given amount of energy in certain frequencies indicates that the crash has progressed to these structural members. The problem is that it is not possible to count on any particular member getting crushed in all crashes. Bumper underride crashes miss the lower structural members, bumper over-rides miss the upper ones and a pole-on-center misses them all. Also, on many vehicles, there is not much structure that is crushed by the time the sensor must decide to trigger the air bag. The crush zone for most cars is only the first 10 inches or less from the front of the bumper. Finally, it is unlikely that any structural member will emit the same vibrational frequencies or energy regardless of how it is struck.

A second theory is that the total of all of the vibrational energy might be indicative that a crash is in progress. As reported in [4], this is an interesting theory, and in fact it works as long as only frontal barrier crashes are considered. The level of vibrations in a 30 MPH frontal barrier impact is on average about 3 times higher than the vibrational level in a 10 MPH frontal barrier impact. However, as reported in [4], the level of vibrations in other crashes, such as a car-to-car side impact, can be several times higher than in the barrier crash, and one can conceive of other impacts such as a collision into a snow bank or crash attenuator where the vibrational level would be much lower. For these reasons, it is unlikely that algorithms based on vibrations can work.

Finally, a careful study of crash pulses will show that there are, in general, no frequencies yet established during the first few milliseconds when the crash must be sensed. Any attempt to use Fourier analysis will only give a false indication of the presence of recurring vibrations as explained in the Appendix to this paper.

It is not the intent here to argue that electronic systems have no virtues. One of their advantages is that other information can be used. It has been pointed out, for example, that there is no need to deploy an air bag on the passenger side if the seat is not occupied. Also, it might be possible to sense the position of the occupant through a proximity sensor and thereby avoid late air bag deployments. The fact that the occupant is wearing a safety belt could also be useful information to change the threshold for air bag deployment. It has even been proposed that the vehicle velocity could be used to modify a sensor algorithm, but since it is velocity change and not velocity that causes injury, it is unlikely that knowledge of the vehicle velocity would be conclusive. In any case, all of these advantages are subsidiary to the main function of a crash sensor system, which is to deploy the air bag when it is needed and avoid deployment when it is not. Based on the arguments presented, it is unlikely that an electronic system using only passenger compartment acceleration information can perform this function.

AN EXAMPLE

Although several suppliers of single point sensors have claimed that they have discovered algorithms which will catch all air bag desired crashes in time, very little has been disclosed about these algorithms or about the basic information or strategy that is used.

One system which has recently been proposed is based on a crash signal processing algorithm which is composed of two parts. One part predicts the displacement of the occupant 30 milliseconds into the future, and disables the sensor if a firing decision has not been reached by the time that this displacement exceeds five inches. This prevents late deployments for the unbelted driver sitting at the mid seat position. The other part checks on the severity of the crash which must be a function of the velocity change. If this severity exceeds some value ß, before the displacement algorithm turns off the sensor, then the air bag is deployed. Since the signal is filtered, at least the high frequency vibrations are not a part of the algorithm.

The problem with this algorithm is that since the impact velocity is not known, it is impossible to predict the velocity change, and thus the Second Collision velocity. This algorithm will fail, for example, in the case

of Figure 8. The Second Collision velocity can be predicted, on the other hand, in the crush zone since that part of the vehicle has already experienced the velocity change. It is unlikely that this algorithm can catch all soft crashes without triggering on many crashes where an air bag is not required. The only advantage over a simple mechanical sensor is the avoidance of some late deployments. Naturally, for occupants that sit closer to the steering wheel, there is still a potential for late deployments and safety belted people are denied the added protection of the air bag for high speed crashes which have a soft beginning. Also, the passenger, who sits much further back from the air bag, will not receive protection in many accidents where the air bag would be required.

CAN ANYTHING BE DONE?

There is a prevailing belief that the problem lies in the structure of the vehicle and that if the vehicle could be made stiffer, for example, then single point sensing would work. Designers of single point sensors sometimes point out that their sensor will not work for all vehicles but only for those with the proper structure, that is, those with a stiff front end.

During a crash an occupant travels for a distance as a free mass until the restraint system (safety belt or air bag) cushions the Second Collision and brings his velocity to that of the vehicle. From that point on, the force on the occupant is proportional to the deceleration of the vehicle. The total distance that energy is absorbed by the restraint system varies from 2 to 6 inches for a seat belt, to 12 to 24 inches for an air bag system. The total crush of the vehicle in a high speed crash approaches 30 inches for full sized vehicles. Therefore, in many cases more of the occupant's kinetic energy is absorbed by the crushing of the vehicle than by the restraint system. Recognizing that it is important that this crush distance be used efficiently, vehicle structure designers have attempted to design vehicles with a constant crush force over the total crush distance. It has recently been recognized that since the occupant can withstand a certain velocity of impact with the restraint system, the vehicle can be decelerated more rapidly at the beginning of the crash. The most efficient crash pulse, therefore, is one that results in a high deceleration at the beginning of the crash followed by a constant deceleration.

Such a crash pulse has further advantages in that it permits the use of a stiffer bumper system making the car less prone to damage in minor accidents and it gives a strong signal to the non-crush zone that can be used to trigger non-crush zone crash sensors. In fact it is commonly heard among single point sensor designers that some cars have too soft a front end to be a candidate for single point sensing, and pressure has been put on the automobile manufacturers to stiffen up their bumper systems so that a passenger compartment mounted sensor will catch a pole crash in time, for example.

One problem, as discussed above, is that many

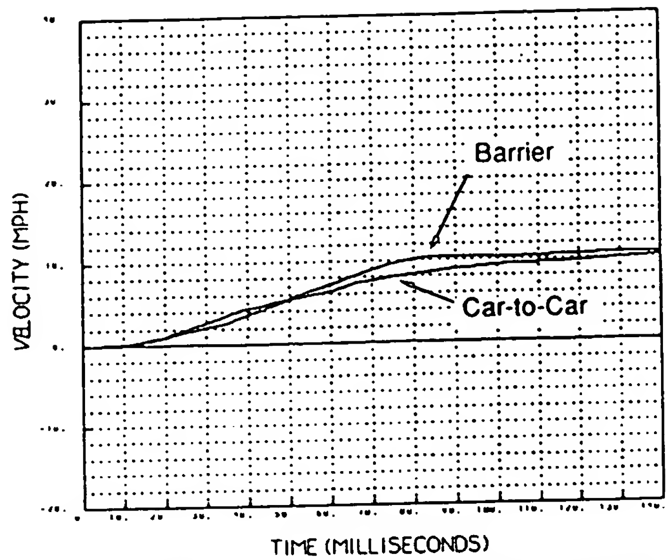


FIG. 9. Velocity Change of a Frontal Car-toCar Crash Compared With a Scaled Barrier Crash

real world crashes (≈40%), do not involve the bumper and, therefore, the areas above and below the bumper must also be stiffened. Also, since hitting only a portion of the front of the vehicle might be softer than hitting the entire front, all areas must be tied in together to provide a uniform stiffness regardless of where the impact takes place. Stiffening the bumper alone is not sufficient.

This strategy might work as long as vehicles only strike rigid objects or maybe other vehicles which have been similarly designed. If a stiff vehicle impacts with a soft vehicle, the crash pulse in the stiff vehicle will be determined not by its structure alone but more by the structure of the softer vehicle. Then, of course, all crash attenuators that now surround rigid objects on the highways will have to be eliminated since they also will cause the pulse to be stretched in the stiffened vehicle.

Let's examine vehicle-to-vehicle impacts since they are probably the most common real world accidents. Vehicle manufacturers run barrier crashes and assume that they represent car-to-car crashes. Figure 9 is a superposition of the velocity change of a staged frontal vehicle-to-vehicle crash along with an equivalent barrier crash. It is important to note that this was a staged crash so that there was no braking which might cause a mismatch of the vehicle bumpers and the accident was a head-on frontal impact. For the first 25 milliseconds the pulses were the same. Something strange then happened, the crash pulse for the car-to-car crash became stiffer until 50 milliseconds at which time it became much softer. The car-to-car pulse is thus different from the barrier pulse and since the slope of the velocity change curve is on average less, an electronic sensor algorithm would likely be fooled into concluding that this was a lower velocity crash.

These vehicles were not examined by the authors, but speculation as to why the pulse had a different shape is as follows. In car-to-car accidents it is rare that the bumpers align perfectly, one usually eventually over-rides the other. In this case, the bumpers initially aligned but

then began bending, one up and the other down. This defeated the bumper shock absorbers preventing them from stroking and making the bumpers initially appear stiffer than in the barrier case. Once the over-ride was complete, the vehicle was much softer since now the structure above the bumper was crushing instead of the rails.

A similar case is shown in Figure 10, where an angle car to car crash is compared with an angle barrier crash. Once again the same conclusions are reached.

The structural design argument is also unreasonable since it is the structure of the softer object in a crash

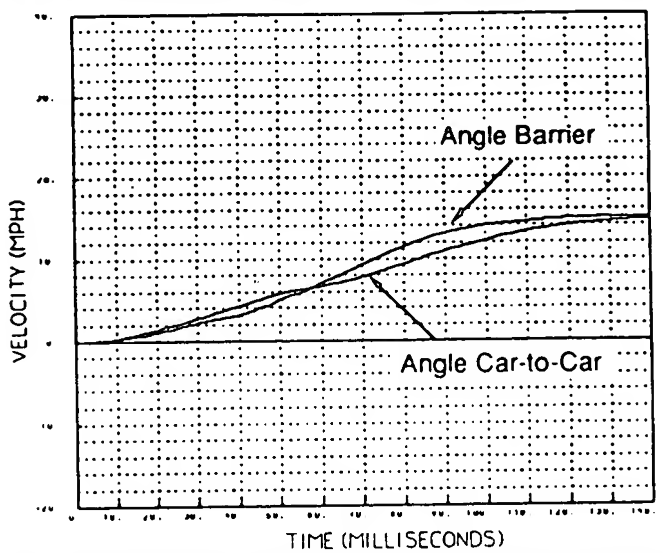


FIG. 10. Car-to-Car and Angle Barrier Velocity Changes.

which determines the crash pulse in both objects. Figure 11 compares the velocity change pulse from a crash where a vehicle impacted the rear of another vehicle and the equivalent barrier crash. The rear of a vehicle is usually significantly softer than the front and this is the case of Figure 11. Note that even the stiffening effect noted in Figure 10 is masked by the softness of the struck vehicle rear. Figure 12, on the other hand, compares the velocity change of both cars, where the velocity change of the struck car has been inverted to allow this comparison. Notice that these velocity change curves are almost identical in spite of the fact that the structures of the two vehicles that were involved in the accident were quite different. (The softer target car actually has a slightly stiffer pulse!) The soft rear end had the effect of significantly stretching the crash pulse in the striking vehicle. Thus, if the single point sensor algorithm will not work universally on all vehicles, it will not work on any vehicle.

In order to discriminate between collisions where an air bag is required from those where it is not, the fact that a vehicle is experiencing a crash and an estimate of the eventual velocity change of that crash must be known. The first fact can be determined anywhere in the vehicle, but the second can only be determined, in the authors opinion, where the car has already experienced the velocity change, the crush zone. Thus, sensors mounted

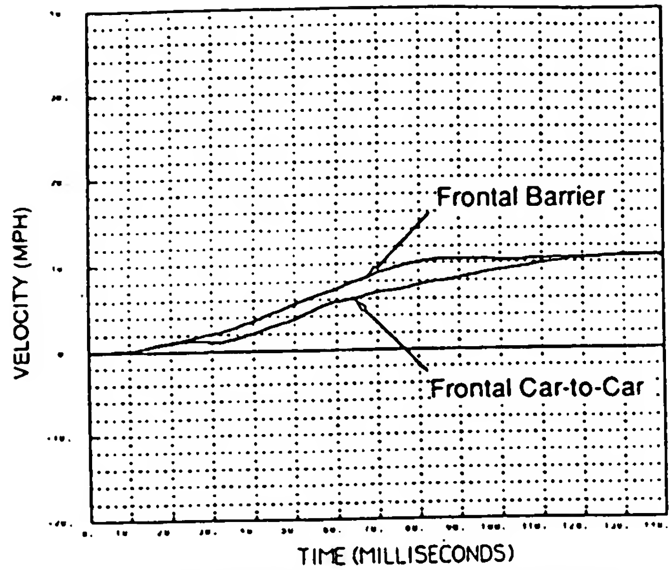


FIG. 11. Frontal Barrier and Car-to-Car Velocity Changes.

in the crush zone are necessary. These sensors need not be expensive and new designs add very little to the cost of an electronic sensing system. When used with an electronic sensor, the advantages of both systems can be realized. When used with a simple diagnostic and mechanical passenger compartment mounted discriminating sensor, the system cost can be substantially reduced while the performance is improved.

There may be valid reasons for designing a vehicle to have a certain crash pulse in a 30 MPH barrier crash, but making the vehicle suitable for single point sensing is not one of them. There are also reasons for making the front of the vehicle softer since this would reduce injury in side impacts and may have a beneficial effect in accidents involving bicycles, motorcycles and pedestrians.

Finally, when the sensor designer states that his single point sensor will not work on all vehicles, ask him what would happen if his properly structured vehicle

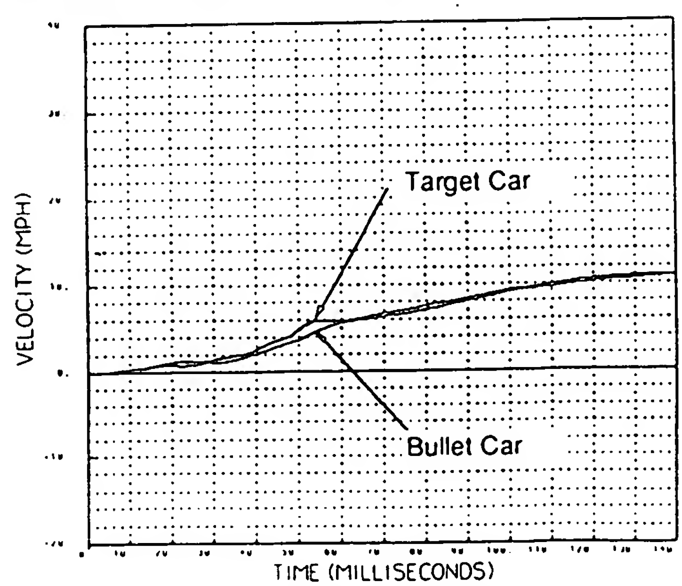


FIG. 12. Car-toCar Front to Rear Target and Bullet Velocity Changes.

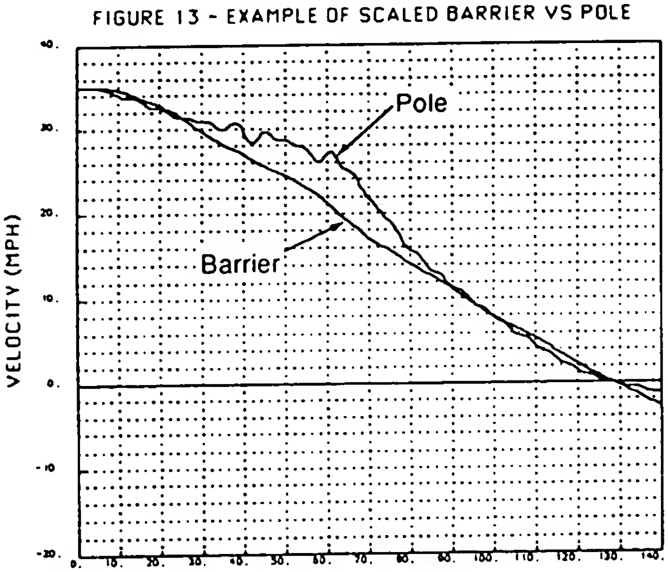
impacts with an improperly structured vehicle. If the vehicles have equal mass, the crash pulses will be the same in both vehicles.

CONCLUSIONS

The authors have presented a simple crash and velocity scaling technique [2,4] which, if used, would have reduced the effort spent in developing single point sensor algorithms. Recent research has led to an improvement in the technique to account for the initial softness and later stiffening of some crash pulses compared to scaled barrier pulses. This will be presented in a future paper but one conclusion is that the situation is actually worse for single point sensors than determined by the scaling techniques. Figure 13 is an example of a scaled barrier velocity pulse compared to a real pole crash. If, as the authors believe, single point sensor algorithms cannot perform properly for the scaled crash cases, they will be even worse in real world crashes. Successful performance on a library of scaled crashes is thus a necessary but not a sufficient condition for single point sensor design.

Because of their ability to use other information, electronic sensors may have some value in the non-crush zone as long as they are supplemental to the primary crash sensors which must be located in the crush zone. When operating on the velocity change of the crash pulse, electronic sensors can be faster than electro-mechanical crash sensors. However, this advantage has been found to be of marginal value, and many electronic crash sensors are in fact slower due to the computational time needed for their algorithms.

FIGURE 13 - EXAMPLE OF SCALED BARRIER VS POLE



It has been argued here that non-crush zone sensing is not sufficient regardless of whether it is electronic or electro-mechanical, at least for the unbelted occupant. This is because there is insufficient information in the crash pulse experienced by the non-crush zone. The problem becomes more complicated when the occupant is wearing a safety belt. Presumably the belt would prevent the occupant from getting into a position where he is resting against the air bag. This may be true of the 50% male with a secure belt system, but cases of the 5% female and of overweight drivers must also be considered. The small driver sits very close to the steering wheel and a late deployment could position him against the air bag. For the overweight occupant, a recent SAE paper has reported that body fat has the same effect as belt slack in permitting the occupant to move out of position.

There are many failure modes of crush zone sensors which have not been addressed in this paper. The reader is referred to a companion paper "Performance of a Crush Sensor for Use with Automobile Air Bag Systems", *By: Breed, D.S., Sanders, W.T. and Castelli, V.* for a discussion of problems with current crush zone sensors. This paper also presents a new low cost concept in crush zone sensing, which permits the tailoring of the sensor to properly respond to a wide variety of impacts to different parts of the front end of the vehicle.

APPENDIX

USE OF FOURIER AND SHOCK SPECTRUM METHODS FOR CRASH DATA ANALYSIS

When trying to determine the response of a mechanical system to a disturbance, Fourier analysis often is used. It is well known that an arbitrary periodic disturbance can be represented as accurately as desired as a sum of harmonic terms of different frequencies, that a disturbance of finite duration can be represented as an integral over frequencies, and that a stationary random disturbance can be characterized by giving the energy contained in each band of frequencies. Furthermore, these representations are determined completely by the disturbance itself.

The Fourier analysis of a disturbance can be useful in estimating the response of a system that is linear, or one that is sensitive only to a small set of frequencies. In either case the response to a harmonic disturbance often is easier to determine than the response to an arbitrary input. For the linear system, the response to the actual disturbance can be found by adding up the responses to each harmonic component. For the one that is sensitive to a small range of frequencies, the Fourier analysis will show how strongly these frequencies are represented in the disturbance, and the presence of the other components will not affect the response.

A transient disturbance, such as crash data up to sensor closure, also can be represented as a sum of harmonic terms, a Fourier Series, or numeric approximation to a Fourier Integral, but the representation applies only in a certain period of time, and the representation will be quite different depending on the period of time that is chosen and on the frequency spacing that is used. Furthermore, the response of a system to a harmonic input of limited duration is not necessarily any easier to determine than its response to the actual signal, and the phase relationships of the various components

will have a critical effect on their combined action. It is much more uncertain to estimate the response of the system as a sum of its responses to the various harmonic components. Even when the system is sensitive only to a small range of frequencies, the sensitivity usually will depend strongly on the duration of the disturbance and on its phase relative to the motion of the sensing mass in a crash sensor, for example.

For these reasons, Fourier Series analysis is seldom used with transient disturbances, unless they are approximately stationary for a period of time long relative to the response time of the system which is not the case for crash sensors. It has been found more useful to prepare a shock spectrum, which shows the maximum responses of simple one-degree-of-freedom systems of various frequencies. If the system is linear, its maximum possible response can be found from the spectrum, and its most probable maximum response can be estimated. If the system is sensitive to a small range of frequencies, then often it may be represented, in that range, as a one-degree-of-freedom system. The representation of the disturbance, and the estimate of the system response, are much more crude than for the case of the periodic or stationary disturbance with its Fourier analysis, but often this is the best that can be done.

As an example of the ambiguity of the Fourier Series representation of a transient signal, consider the very simple case of a single square wave of unit amplitude and 30 millisecond duration. If this is represented by a sum of sine terms, then the sum of these can be made to equal the square wave exactly over any specified duration. If the specified duration is T1, then the frequencies and amplitudes of the first few terms can be calculated to be:

for T1 = 10 ms, frequencies (in Hz) are 314, 942, 1571, ... with amplitudes 1.27, 0.42, 0.25, ...

for T1 = 30 ms, frequencies are 105, 314, 524, ... with amplitudes 1.27, 0.42, 0.25, ...

for T1 = 50 ms, frequencies are 63, 126, 188, 251, 314, ... with amplitudes 0.83, 0.58, 0.04, 0.11, 0.25, ...

If the system, for example, were sensitive to frequencies around 300 Hz, then the amplitude would be 1.27, 0.42, or 0.25 depending on which of these were used!

A similar Fourier analysis of a single spike would show similar results with the added complication that the phasing of the spike relative to the beginning of the data could give a false indication of a frequency. Crash data up to the time of sensor closure usually consists of a number of discrete spikes with little evidence of an underlying frequency. A Fourier analysis could completely miss the significance of a series of spikes which are almost equally spaced in time due to a varying phase relationship. A mechanical system, however could respond strongly to this series if the timing of the spikes was in the range of the natural frequency of the device. Thus, in this case, the Fourier analysis would give the false impression that the system would not be affected by the vibrations in the crash while in fact a strong effect would exist.

For these reasons, it is not proper to use Fourier analysis to determine the presence of resonant frequencies in crash data which could alter sensor response.

A second reason for using Fourier analysis is also fraught with danger. There have been attempts to determine crash severity using an algorithm based on frequency analysis. Such systems work as long as crashes of the same type are studied. This is because the vibrations in a crash tend to scale with velocity change for similar crashes. The level of vibrations in a 30 MPH barrier crash, for example, can be approximately twice the level in a 15 MPH barrier crash. However, this scaling does not carry over from one type of crash to another. The level of vibrations in the bullet car in an 8 MPH velocity change collision into the side of another moving car, for example, can be many times the level in a 12 MPH barrier crash.

REFERENCES

1. Breed, D.S., Castelli, V. "Problems in Design and Engineering of Air Bag Systems", SAE 880724, 1988.

2. Breed, D.S., Castelli, V. "Trends in Sensing Frontal Impacts", SAE 890750, 1989.

3. Castelli, V., Breed, D.S. "Trends in Sensing Side Impacts", SAE 890603, 1989.

4. Breed, D.S., Castelli, V. and Shokoohi, F. "Are Barrier Crashes Sufficient for Evaluating Air Bag Sensor Performance?", SAE 900548, 1990.

5. Breed, D.S., Sanders, W.T. and Castelli, V. "Performance of a Crush Sensor for Use with Automobile Air Bag Systems", Automotive Technologies International, Inc. Report 14102, November, 1991.

6. Mertz, H.J., Driscoll, G.D., Lenox, J.B., Nyquist, G.W., and Weber, D.A. "Response of Animals Exposed to Deployment of Various Passenger Inflatable Restraint System Concepts for a variety of Collision severities and Animal Positions", SAE 826047, 1982.

7. Prasad, A.K. "Energy Dissipated in Vehicle Crush - A Case Study Using Repeated Test Technique", SAE 900412, 1990.